08 May 1984, 8:00 am - 10:00 am

Reinforced Flow Retardation Structure at Henshaw Dam

Dennis S. Tarnay

Federal Energy Regulatory Commission

Reinforced Flow Retardation Structure at Henshaw Dam

Dennis S. Tarnay
Civil Engineer, Federal Energy Regulatory Commission, Washington, D.C., U.S.A.

SYNOPSIS The Henshaw Dam is a semi-hydraulic earthfill structure. The seismic studies indicated that the dam could fail by liquefaction during a strong seismic motion. To ensure the integrity of the dam, the reservoir storage was reduced, the old spillway reconstructed, and a new reinforced flow retardation structure was built immediately downstream from the existing dam.

INTRODUCTION

The Henshaw Dam is located on the San Luis Rey River in northern San Diego County, California. It is a semi-hydraulic earthfill structure 35.5 m (110 feet) high and 594.0 m (1,950 feet) long. The dam was completed in 1923 and modified in 1928. The reservoir behind the dam has a capacity of 239,200,000 m^3 (194,000 acre-feet) at elevation 2,727.0 feet above m.s.l., and receives runoff from a drainage area of 525.8 km^2 (203 square miles). The storage is made up by retaining the flows of the San Luis Rey River and by groundwater which is pumped into the reservoir from about 25 wells located at the upper end of the reservoir. The storage is used as domestic, municipal, and agricultural water by city of Vista and by surrounding agricultural land in northwestern San Diego County.

The safety of the Henshaw Dam was officially questioned by the Division of Dam Safety of the State of California after the hydraulically filled Lower San Fernando Dam was seriously damaged by an earthquake in 1971. It was indicated that the Henshaw Dam, which has approximately the same height as the Lower San Fernando Dam, could have similar properties as the Lower San Fernando Dam and may also fail during a large earthquake. The Henshaw Dam, similarly as the Lower San Fernando Dam, is located in a region of high seismic risk. The San Jacinto fault located 32 km (20 miles) north-easterly of Henshaw Dam has been the most active in Southern California in the past 30 years. The Elsinore fault passes adjacent to the dam and branches may pass directly under the base of the dam. Investigations and review of the recorded data indicated that the Elsinore fault may create safety hazard to the dam due to fault displacement and shaking (liquefaction) of the embankment. It was also determined that the dam could not meet current standards for dynamic safety and that in the event of a large magnitude earthquake the dam could suffer partial or total failure. There is also a chance that the fault will move during the economic life of the dam. As a result, the State of California in 1973 ordered to maintain the water elevation in the reservoir at 2,665.0 feet above m.s.l., which is equivalent to about 12,330,000 m^3 (10,000 acre-feet) of water, until the dam is modified and made safe for larger storage. It was agreed that the proposed modification would include: (1) permanent reduction of the reservoir storage capacity from 240,000,000 m^3 (194,000 acre-feet) to 62,000,000 m^3 (50,000 acre-feet), (elevation from 2,727.0 feet above m.s.l. to elevation 2,690.0 feet above m.s.l.), or to about 1/4 of its total capacity, (2) reconstruction of the existing spillway by lowering its crest elevation from 2,727.4 feet above m.s.l. to elevation 2,690.0 feet above m.s.l., and adding a new notch and chute, and (3) construction of a new reinforced flow retardation structure immediately downstream of the dam. The dam and the flow retardation structure are shown in Figure 1 an 2.

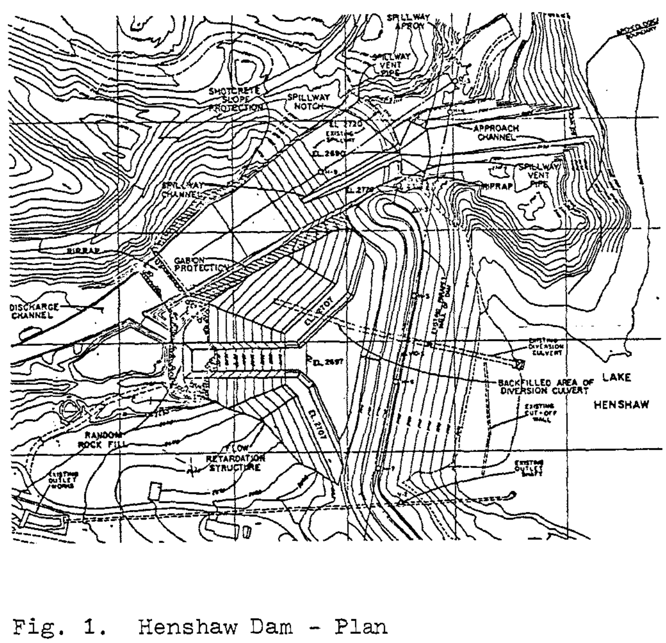

Fig. 1. Henshaw Dam - Plan

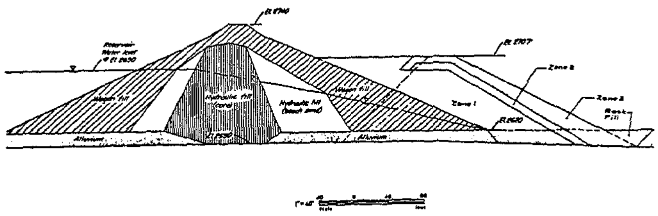

Fig. 2. Henshaw Dam - Section

GEOLOGY AND EARTHQUAKE HAZARD

The reservoir and the dam occupies part of the alluviated Warner Basin of approximately 108.0 km^2 (42 square miles). The basin represent a graben type structure of downdropped blocks resulting from different vertical movement along several faults. The rocks exposed and underlying the sediments of the basin are primarily granitic rocks. The bedrock in the damsite area is heavily weathered quartz diorite. Numerous pegmatities have intruded the rock, and there are several slickensided surfaces.

Several major faults were identified in the vicinity of the Henshaw Dam including the Elsinore fault on the southwest edge of the reservoir, the Agua Tibia and Aguanga faults near the north eastern edge of the Warner Basin, and the Agua Caliente, Lancaster and Hot Springs faults further to the northeast.All this faults together with other subparallel faults are collectively designated as the Elsinore fault zone which is 13 to 20 km (8 to 12 miles) wide at Lake Henshaw. The San Jacinto and San Andreas fault zones parallel the Elsinore fault zone at the distance of 35 km (22 miles) and 76 km (47 miles) respectively to the northeast. The Elsinore fault zone is one of the major faults of southern California extending from Lake Elsinore to Mexico. The potential hazards to Henshaw Dam arise from the possible effects of both strong ground motion and surface fault breaks. Ground motion could result in a major embankment failure such as that which occured at the Lower San Fernando Dam in 1971.

The first hazard to Henshaw Dam is the possibility of a major slide into the reservoir, similar to which occured at the Lower San Fernando Dam. The second is the possibility of piping caused by lateral or vertical movements along a fault plane cutting through Henshaw Dam.

According to Dr. J. N. Brune, professor of geophysics, University of California at La Jolla, and other experts, the Henshaw Dam is located in a region of high seismic risk. A large earthquake,which can occur very near the dam any time, could result in high ground acceleration and velocities. The granitic rocks on both sides of the fault and directly beneath the dam, can create high stresses and very efficient propagation of high frequency energy, and may cause fault slippage along a branch of the fault passing directly beneath the dam. The expected acceleration,according to Dr. Brune,could have a magnitude of 6 to 7.5 on the Richter scale.

INVESTIGATIONS

A series of geotechnical investigations were conducted to determine the geological and seismic characteristics of the region and vicinity surrounding the dam, and the material properties of the dam embankment.

The first phase of investigations included the collection and analysis of sufficient soil and geological data and seismic informations to determine whether it would be necessary to carry out an extensive dynamic stability analysis of the Henshaw Dam. A soil sampling and testing program was performed to determine the characteristics of embankment materials in the dam. In addition, records from the original construction of the Henshaw Dam and subsequent modifications were collected and reviewed. Investigation of the existing dam, the foundation of the proposed flow retardation structure, the channel downstream from the spillway, and the borrow and quarry areas were conducted in several stages. The investigations included: (1) soil borings, (2) a number of laboratory tests of material from the dam, (3) a seismic refraction survey of the channel downstream of the dam,(4) test pits and bulldozer trenches in the foundation of the proposed flow retardation structure, (5) pits to define the depth of burial of the lower part of the spillway chute, and (6) borings and several laboratory tests from the vicinity of the dam.

Results of the investigations were reviewed by Dr. H. B. Seed, particularly the need for a full dynamic analysis. Subsurface investigations has confirmed that the Henshaw Dam could not meet the current safety requirements. Therefore, it was proposed not to proceed with the dynamic stability analysis of the dam, but rather continue with the investigations directed toward modifications of the Henshaw Dam.

Prior to design of the flow retardation structure, the second phase investigation vent on, which included excavation of the test pits, diamond core drilling, and soil sampling. A total of 21 test pits were excavated in the foundation, the borrow and quarry areas, the lower spillway chute area, and the downstream channel. Exploration of the foundation was done by 4 angled holes to determine the extent of faulting and by 5 vertical borings in which soil sampling was done One angle core hole was drilled in the right abutment of the dam to determine the quality of rock adjacent to the spillway, and 3 core holes were drilled in the spillway. Vertical core holes were drilled in the borrow area, in the spillway forebay, and in the quarry area located 2.4 km (1.5 miles) north of the dam. Other field and laboratory work included in-situ density test in the wagon filled material of the dam, the downstream spillway channel, and in the borrow area near the spillway. The grain size curves were developed for materials from the borrow areas, stilling basin, wagon fill and stream bed alluvium. Maximum density values were performed applying the ASTM D1557-70 method. Two types of static loading triaxial tests were performed on samples from the wagon fill, the borrow area, and the stilling basin: (1) the consolidated-drained tests with volume change measurements, and (2) the consolidated-undrained tests with pore pressure measurements.

In addition to exploration and testing, several special studies have been conducted which are directly or indirectly related to geotechnical aspects of the project. These included: (1) a study of faulting in the vicinity of the dam,(2) a report on the seismic hazard at the dam by Dr. J. N. Brune, (3) an environmental impact report which included certain considerations affecting geotechnical design, and (4) a surface mapping of the Elsinore fault zone in the vicinity of the dam by the California Division of Mines and Geology (CDMG).

On the basis of geomorphic evidence, the CDMG has dated the recency of movement on most of the fault traces at the vicinity of Lake Henshaw as Holocene age (last 11,000 years). For this reason, the segment of the fault zone near Lake Henshaw was termed as "active", and the area adjacent to the fault traces designated as a Special Study Zone in accordance with the Geologic Hazard Zones Act.

FLOW RETARDATION STRUCTURE

The new flow retardation structure is a zoned earth and rock embankment built immediately downstream of the old dam, overlying the vagon fill which forms the downstream slope of the old dam. It is a 30 m (100 feet) high and 180 m (600 feet) long stabilizing structure which, it is believed, would prevent loss of the reservoir in case that the Henshaw Dam fail during a major earthquake. The primary function of the flow retardation structure is: (1) to retain reservoir water in the event of failure of the Henshaw Dam by an earthquake, (2) to prevent catastrophic discharge of water downstream, (3) to provide added stability to the downstream slope of the old dam, and (4) to ensure resistance to,and control of piping in the old dam in the event of fault displacement. In the middle of the flow retardation structure there is a 3 m (10 feet) deep and 15 m (50 feet) wide channel armored with reinforced rockfill. In the event of a failure of the old embankment during an earthquake when the reservoir is full (62,000,000 m^3 or 50,000 acre feet), this channel will safely release the water from the reservoir and prevent catastrophic flooding downstream.

Similar concept of flow through reinforced rockfill has been implemented in rockfill structures in Australia, Mexico, South Africa, and California with very good results. The structures have performed successfully also when subjected to throughflow of water during floods which have overpopped the partially completed dams.

The principal material zones in the flow retardation structure are:

Zone 1. Random (supplementary) fill, consisting of sand, silty sands and gravelly sands filled up to elevation 2,680.0 feet above m.s.l. It would accomodate fault movement in the foundation. Total volume approximately 50,000 m^3 (65,000 cubic yards).

Zone 2. Transition zone, consisting of well graded coarse sand and gravel, filled up to elevation 2,690.0 above m.s.l. This is the so called "self-healing" zone capable of preventing piping in case of fault offseing. Total volume approximately 35,000 m^3 (45,000 cubic yards).

Zone 3. Rockfill with 2.5 cm (1 inch) minimum size. It is reinforced to make it stable against throughflow and overflow of water as well as deep and shallow sliding. Total volume approximately 46,000 m^3 (60,000 cubic yards).

The schematic plan and sections of the flow retardation structure are shown in Figure 3,4 and 5.

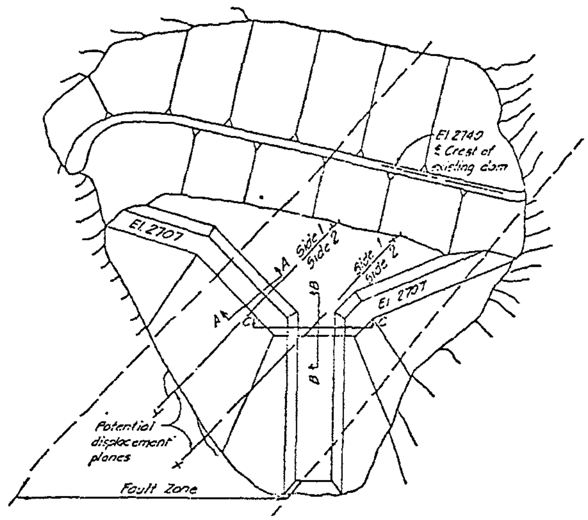

Fig. 3. Flow Retardation Structure-Plan

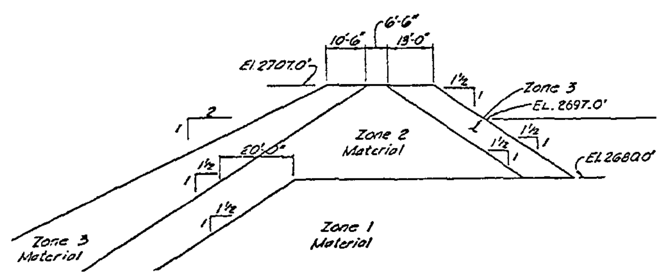

Fig. 4. Flow Retardation Structure-Section A-A

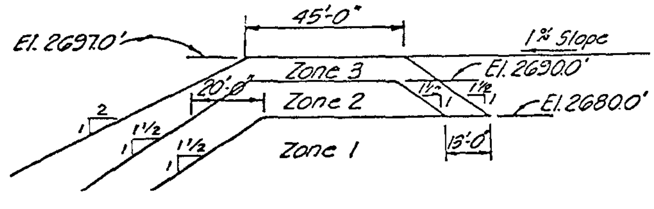

Fig. 5. Flow Retardation Structure-Section B-B

Before the final design of the flow retardation structure was outlined, a stability analysis was performed on the existing dam assuming that an earthquake had resulted in liquefaction of the hydraulic fill. The results of the analysis indicated that the slip circles with minimum safety factors do not pass through the toe of the dam, and that both upstream and downstream embankment failure could occur. Also, earlier studies had shown that loading of the downstream toe of the dam embankment by an earth or rockfill structure would improve the stability of the downstream slope. It was also concluded that if a downstream slope failure can be prevented by a berm or flow retardation structure, then a progressive failure would develop, similar to that at Lower San Fernando Dam. The assumed failure is shown in Figure 6.

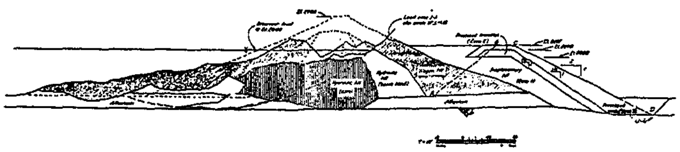

Fig. 6. Henshaw Dam-Section-Failure Simulation

The flow retardation structure was analyzed assuming 6 loading conditions. Four without and two with reinforcement using both Bishop' and the ordinary method of slices. The results indicated that the flow retardation structure would need rockfill reinforcement to bring the safety in the transition and rockfill zones to not less than 1.2. The area between the structure and the south wall of the spillway is highly erodible, therefore, it was decided that any water flowing through or over the structure should be restricted to the central area of the flow retardation structure. This condition led to the shape of the structure shown in Figure 3.

The design criteria for material properties were as follow:

Material	c' (psf)	ϕ (deg)	γ (pcf)
Wagonfill	320	35	120
Hydraulic Fill Dry	600	25	120
Hydraulic Fill Liqfd.	0	0	120
Supplementary Fill	800	34	120(130 sat.)
Processed Transition	0	38	125(135 sat.)
Processed Rock	0	45	130(140 sat.)
Alluvium	0	35	120

Other design criteria: Maximum credible earthquake of 0.6 g and a corresponding sustained acceleration of 0.2-0.3 g. Aftershock of 0.15 g. Maximum fault offset of 1.5 m (5 feet) in vertical and horizontal direction, and 2.1 m (7 feet) in diagonal or oblique direction. Factor of safety for static loading equal to 1.5 and for static plus earthquake to 1.2. Reservoir elevation at 2,690.0 feet above m.s.l. and top of the flow retardation structure at 2,700.0 feet above m.s.l.

The surface reinforcement adapted for the FRS consists of a 5 foot by 13.4 foot grid of #8 bars backed by 6 gauge by 2 inch galvanized chain link mesh, with horizontal anchor bars into the rockfill at each intersection of the surface grid bars. The horizontal anchor bars are 5 foot apart horizontally and 6 foot vertically. For calculating the need for reinforcement against deep seated sliding, the Shand and Pells (1970) method was applied using the modified version of Bishop's simplified slip circle analysis. The modified Bishop equation was used to calculat the minimum factors of safety for a range of lues (0 to 600 psf) of the resisting stress " induced by the reinforcement. The proposed re forcement is shown in Figure 7.

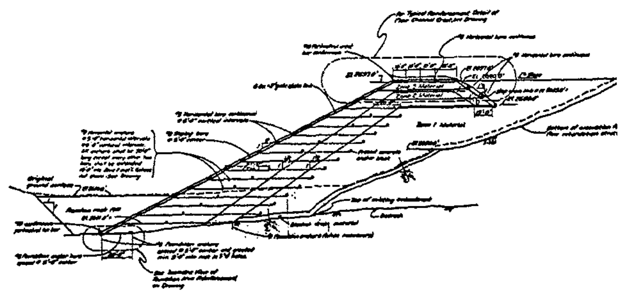

Fig. 7. Reinforcement of the FRS-Section

CONCLUSION

The reinforced flow retardation structure sho stabilize the Henshaw Dam and prevent catastr phic flooding downstream of the dam during a large earthquake, which could occur any time the vicinity of Lake Henshaw. The reinforced structure should prevent surface sloughing an revelling when overflow occurs through the em bankment. It should also prevent deep seated slip circle failures in the embankment. The m dification of the Henshaw Dam was completed i 1981.

ACKNOWLEDGEMENT

I would like to express my appreciation to Ph L. Wagner of Leeds, Hill and Jewett, Inc., Sa Francisco, California, for his help to assist with documentation, references to literature slides showing the construction phases of the reinforced flow retardation structure at the Henshaw Dam.

NOTE

The views presented in this paper are those o the author and not necessarily of the Federal Energy Regulatory Commission (FERC).

REFERENCES

Earth Reinforced Dams: First in U.S.(1983).Ci Engineering, October, p. 60-63.

Final Environmental Impact Report of the Modi cation of Henshaw Dam and Warner Ranch Ground Water Program (1979). Prepared for the Vista Irrigation District by Leeds, Hi and Jewett, Inc., San Francisco, Californi

Henshaw Dam Modification (1980). Technical Mem randum No.1,2 and 3. Prepared for the Vist Irrigation District by Leeds, Hill and Jewett, Inc., San Francisco, California.

Hill, A. Raymond (1973). The Henshaw Dam Problem, San Francisco, California.

Shand, Ninham and P.J.N. Pells (1970). Experie ce in the Design and Construction of Reinforced Rockfill Dams. Commission Internati nale Des Grands Barrages, Montreal, Canada